# WEATHER AND LATE SPRING MIGRATION OF BIRDS INTO SOUTHERN ONTARIO

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Many studies of the correlations between bird migration and various aspects of weather have been published. These were reviewed by Lack (1960*b*). Recent North American authors believe that spring migration occurs with following winds (Bagg et al., 1950; Raynor, 1956; Graber and Cochran, 1960; Drury and Keith, 1962). Major spring influxes of migrants usually occur with high pressure areas to the east and/or low pressure areas to the west (Bagg et al., op. cit.). No recent study has proposed that barometric pressure, per se, has an important influence on migration (Lack, 1960*b*). It is generally believed that light winds are more favorable to migration than are strong winds (Lack, 1960*a*, *b*). Major waves of vernal migrants usually move through after the passage of a warm front and they usually stop migrating when they encounter a cold front (Bagg et al., op. cit.: Raynor, op. cit.). Temperature has been considered by some, especially in Europe, to have a great deal of influence on the timing of migration. Heavy cloud or rain is commonly believed to reduce the volume of migration (Lack, 1960*a*, *b*).

The present paper is an analysis of the late spring migrations into southern Ontario in the years 1961, 1962 and 1963.

## METHODS

It is generally accepted that late spring influxes are less dependent on warm weather with southerly winds than are earlier ones (Bagg et al., op. cit.: Lack, 1960*a*). Thus the period of study was restricted to the months of May in 1961 and 1963 and to the period of 24 April to 24 May, 1962. The 1962 period was advanced by one week because a major wave of late spring migrants arrived unusually early, but in weather conditions similar to those which were prevalent on most other days with major waves.

The flights recorded in southern Ontario were assumed to have originated south of Lakes Erie and Ontario. Accordingly, correlations were made with the weather conditions both in Ontario and south of the lower Great Lakes.

*Selection of data.*—All of the meteorological data used were taken from the U.S. Weather Bureau daily surface maps. The data used included the temperature, dew point, wind direction, wind velocity and cloud cover at 0100 EST at Toronto, Ontario and the means of these at Cleveland, Ohio, Columbus, Ohio, and Pittsburgh, Pennsylvania. Areas of rain and locations of pressure systems and fronts at 0100 were noted. Since most late spring migrants move at night, the conveniently obtained 0100 conditions were considered suitable.

The averages of the 0100 wind directions at Cleveland, Columbus, Pittsburgh and Toronto were placed into 3 categories. Winds between SSE and WSW were classified as *following*. Those between WNW through N to ESE were *opposing*. Winds between WNW and WSW and between ESE and SSE were called *side* winds. These categories were decided upon after consideration of the flight directions of nocturnal migrants during May near Hamilton, Ontario, as revealed by my lunar observations. In some cases, the combined category *not following* was used for side and opposing winds.

When considering humidity, the number of degrees in the difference between the actual temperature and the dew point temperature was taken as a reflection of relative humidity. A small difference indicates a high relative humidity. While not exact, this measure is convenient and reasonably accurate within the fairly narrow range of temperatures present during the period of study.

Ornithological data were assembled from the spring migration reports in *Audubon Field Notes* (August issues) and from those in the Federation of Ontario Naturalists' *Bulletin* and in its successor, *The Ontario Naturalist* (Sept. issues). In addition, my observations of nocturnal migrants passing in front of the moon (5 nights during the period of study; 19 in May of 1964 and 1965) and the results of a daily census made in 1962 were used.

Each day was classified as type A, a major-wave day; type B, a minor-wave day; or type C, a little-movement day. This was done by assigning numbers of points to stations in Ontario south of latitude 46°30′ which made regular observations of migration. The number of points assigned varied from 0 for reports of no movement to 5 for very heavy movement. Points were not assigned for concentrations of migrants believed to be grounded. The totals were weighted by doubling the number of points assigned to Long Point and Point Pelee. These two stations were better studied and the extent of migration was, because of concentration effects, considered easier to estimate accurately there. Days with a total of 20 or more points were type A, of 10 to 19, type B and of 0 to 9, type C.

Of the 93 days studied, there were 14 type-A days (7, 13, and 14 May, 1961; 28 and 29 April, 1962; 5, 6, 13, 14, 15, 16, 17, and 19 May, 1962; 9 May, 1963), 7 type-B days (1 and 28 May, 1961; 26, 27, and 30 April, 1962; 18 May, 1962; 3 May, 1963), and 72 type-C days.

It was recognized that the diurnal observations which exerted the dominant influence on the classification of days as A, B, or C might not give a true idea of the volume of migration. In particular, grounded waves of migrants might be mistaken for onrushing waves and migrants, especially nocturnal ones, might pass over undetected. However, in view of the good results of others who used diurnal data (Bagg et al., op. cit.; Raynor, op. cit.), the classical wave pattern obtained, and the agreement between lunar and diurnal observations, useful results were expected. In the present study, major waves were isolated satisfactorily, but very few minor waves were recorded. Since lunar observations show some movement almost every hour of observation, many minor waves must have been missed. Since the averages of weather parameters on type-B days are based on only 7 days' data, they are not considered to be very reliable. This paper considers primarily the differing relationships between type-A days, type-C days, and the weather.

TABLE 1

MIGRATION CORRELATED WITH AIR MASSES, WIND, FRONTS, AND RAIN

| 0100 weather conditions in southern Ontario | Days weather present | No. days weather at left and various types migration expected together if no correlation (± standard deviation)* | | |
|---|---|---|---|---|
| | | Type A | Type B | Type C |
| H to E | 39 | 5.9 ± 1.9 | 2.9 ± 1.3 | 30 ± 4.2 |
| H to E; wind following | 27 | 4.1 ± 1.7 | 2.0 ± 1.2 | 21 ± 3.9 |
| H to E; wind not following | 12 | 1.8 ± 1.3 | 0.90 ± 0.89 | 9.3 ± 2.9 |
| L to W | 28 | 4.2 ± 1.7 | 2.1 ± 1.2 | 22 ± 3.9 |
| L to W; wind following | 21 | 3.2 ± 1.6 | 1.6 ± 1.1 | 16 ± 3.6 |
| L to W; wind not following | 7 | 1.1 ± 0.99 | 0.53 ± 0.70 | 5.4 ± 2.2 |
| H to E; L to W | 23 | 3.5 ± 1.6 | 1.7 ± 1.1 | 18 ± 3.7 |
| H to E; L to W; wind following | 17 | 2.6 ± 1.5 | 1.3 ± 1.0 | 13 ± 3.3 |
| H. to E; L to W; wind not following | 6 | 0.90 ± 0.92 | 0.45 ± 0.65 | 4.6 ± 2.1 |
| H to E and/or L to W | 44 | 6.6 ± 1.9 | 3.3 ± 1.3 | 34 ± 4.2 |
| H to E and/or L to W; wind following | 31 | 4.7 ± 1.8 | 2.3 ± 1.3 | 24 ± 4.0 |
| H to E and/or L to W; wind not following | 13 | 2.0 ± 1.3 | 0.98 ± 0.92 | 10 ± 2.9 |
| Neither H to E nor L to W | 49 | 7.4 ± 1.9 | 3.7 ± 1.3 | 38 ± 4.2 |
| Neither H to E nor L to W; wind following | 1 | 0.15 ± 0.39 | 0.08 ± 0.27 | 0.76 ± 0.88 |
| Neither H to E nor L to W; wind not following | 48 | 7.2 ± 1.9 | 3.6 ± 1.3 | 37 ± 4.2 |
| Following winds | 25 | 3.8 ± 1.7 | 1.9 ± 1.2 | 19 ± 3.8 |
| Side winds | 25 | 3.8 ± 1.7 | 1.9 ± 1.2 | 19 ± 3.8 |
| Opposing winds | 41 | 6.2 ± 1.9 | 3.1 ± 1.3 | 32 ± 4.2 |
| Calm winds | 2 | 0.30 ± 0.54 | 0.15 ± 0.38 | 1.6 ± 1.2 |
| Cold front to S or E | 28 | 4.2 ± 1.7 | 2.1 ± 1.2 | 22 ± 3.9 |
| Cold front to N or W | 30 | 4.5 ± 1.8 | 2.3 ± 1.2 | 23 ± 4.0 |
| No cold fronts near | 35 | 5.3 ± 1.8 | 2.6 ± 1.3 | 27 ± 4.1 |
| Warm front to S or W | 6 | 0.90 ± 0.92 | 0.45 ± 0.65 | 4.6 ± 2.1 |
| Warm front to N or E | 20 | 3.0 ± 1.5 | 1.5 ± 1.1 | 16 ± 3.5 |
| No warm fronts near | 67 | 10 ± 1.7 | 5.0 ± 1.2 | 52 ± 3.8 |
| Warm sector | 15 | 2.3 ± 1.4 | 1.1 ± 0.97 | 12 ± 3.1 |
| Rain present | 25 | 3.8 ± 1.7 | 1.9 ± 1.2 | 19 ± 3.8 |

* See "Methods" for explanation.

† The symbols + and − indicate positive and negative correlations between the type of weather at the left and the type of migration at the top of the column. IS, S, and HS indicate insignificant ($P > 0.05$), significant ($0.05 \geqslant P > 0.003$), and highly significant ($P \leqslant 0.003$) correlations.

TABLE 1 (*cont.*)

| | Days weather and various types migration occurred together* | | | Occurred-expected difference as a multiple of the standard deviation* | | | Significance of difference between observed and expected numbers of days† | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C |
| H to E | 13 | 6 | 20 | 3.9 | 2.4 | –2.4 | +HS | +S | – S |
| H to E; wind following | 12 | 5 | 10 | 4.7 | 2.5 | –3.5 | +HS | +S | – HS |
| H to E; wind not following | 1 | 1 | 10 | –0.64 | –0.10 | 0.25 | – IS | – IS | +IS |
| L to W | 12 | 4 | 12 | 4.5 | 1.6 | –2.5 | +HS | +IS | – S |
| L to W; wind following | 12 | 3 | 6 | 5.6 | 1.3 | –2.9 | +HS | +IS | – S |
| L to W; wind not following | 0 | 1 | 6 | –1.1 | 0.68 | 0.26 | – IS | +IS | +IS |
| H to E; L to W | 11 | 4 | 8 | 4.7 | 2.0 | –2.7 | +HS | +IS | – S |
| H to E; L to W; wind following | 11 | 3 | 3 | 5.8 | 1.7 | –3.2 | +HS | +IS | – S |
| H to E; L to W; wind not following | 0 | 1 | 5 | –0.98 | 0.84 | 0.17 | – IS | +IS | +IS |
| H to E and/or L to W | 14 | 6 | 24 | 4.0 | 2.0 | –2.4 | +HS | +S | – S |
| H to E and/or L to W; wind following | 13 | 5 | 13 | 4.7 | 2.1 | –2.8 | +HS | +S | – S |
| H to E and/or L to W; wind not following | 1 | 1 | 11 | –0.75 | 0.02 | 0.32 | – IS | +IS | +IS |
| Neither H to E nor L to W | 0 | 1 | 48 | –4.0 | –2.0 | 2.4 | – HS | – S | +S |
| Neither H to E nor L to W; wind following | 0 | 1 | 0 | –0.39 | 3.4 | –0.89 | – IS | +IS | – IS |
| Neither H to E nor L to W; wind not following | 0 | 0 | 48 | –3.9 | –2.7 | 2.6 | – HS | – S | +S |
| Following winds | 12 | 6 | 7 | 5.0 | 3.5 | –3.3 | +HS | +HS | – S |
| Side winds | 2 | 0 | 23 | –1.1 | –1.6 | 0.96 | – IS | – IS | +IS |
| Opposing winds | 0 | 1 | 40 | –3.3 | –1.6 | 2.0 | – HS | – IS | +S |
| Calm winds | 0 | 0 | 2 | –0.56 | –0.39 | 0.37 | – IS | – IS | +IS |
| Cold front to S or E | 0 | 0 | 28 | –2.5 | –1.8 | 1.6 | – S | – IS | +IS |
| Cold front to N or W | 12 | 5 | 13 | 4.3 | 2.2 | –2.6 | +HS | +S | – S |
| No cold fronts near | 2 | 2 | 31 | –1.8 | –0.50 | 0.95 | – IS | – IS | +IS |
| Warm front to S or W | 2 | 0 | 4 | 1.2 | –0.70 | –0.31 | +IS | – IS | – IS |
| Warm front to N or E | 10 | 4 | 6 | 4.5 | 2.3 | –2.7 | +HS | +S | – S |
| No warm fronts near | 2 | 3 | 62 | –4.8 | –1.7 | 2.7 | – HS | – IS | +S |
| Warm sector | 9 | 3 | 3 | 4.9 | 1.9 | –2.8 | +HS | +IS | – S |
| Rain present | 1 | 2 | 22 | –1.7 | 0.10 | 0.69 | – IS | +IS | +IS |

*Methods of analysis.*—Factors such as different categories of wind direction and the presence of pressure systems and fronts in various positions were considered using the method outlined by Raynor (op. cit.). In this method, the number of days on which a specific type of migration (A, B, or C) and a specific weather condition occurred together is compared with the number of days on which both that type of migration and that weather condition would be expected to occur together if there were no correlation between the volume of migration and that weather factor. In each test, the quantity,

TABLE 2

MEANS OF NUMERICAL WEATHER PARAMETERS WITH VARIOUS TYPES OF DAYS

| Weather parameter at 0100 EST | Arithmetic mean ± standard deviation | | | | Significance of A–C difference |
|---|---|---|---|---|---|
| | Type-A days (major wave) | Type-B days (minor wave) | Type-C days (little mig.) | All days together | |
| Units: F. | | | | | |
| Temperature—Toronto | 58.8±7.1 | 53.0±9.5 | 47.2±7.0 | 49.2±8.6 | HS |
| Temperature—South of Lake Erie | 64.3±4.1 | 54.1±8.4 | 50.8±8.2 | 53.0±8.9 | HS |
| Temperature—Dew point interval—Toronto | 7.6±5.6 | 12.3±6.0 | 8.6±5.0 | 8.8±5.3 | IS |
| Temperature—Dew point interval—South of Lake Erie | 9.6±4.0 | 10.1±3.5 | 8.2±4.4 | 8.5±4.3 | IS |
| Temperature—Dew point interval increase over day before—Toronto | –5.2±7.9 | -0.14±7.0 | 0.89±5.4 | 0.01±6.3 | HS |
| Temperature—Dew point interval increase over day before—South of Lake Erie | –1.6±4.1 | 0.14±3.7 | 0.15±5.9 | -0.08±5.5 | IS |
| Units: Knots | | | | | |
| Wind velocity—Toronto | 5.8±3.3 | 6.7±5.5 | 7.2±4.5 | 6.9±4.5 | IS |
| Wind velocity—South of Lake Erie (Cleveland, Columbus, Pittsburgh) | 5.9±2.6 | 4.3±1.8 | 6.7±2.6 | 6.4±2.6 | IS |
| Units: Tenths of sky | | | | | |
| Cloud cover—Southern Ontario | 3.8±4.0 | 4.1±4.4 | 4.6±4.3 | 4.5±4.3 | IS |
| Cloud cover—South of Lake Erie | 4.2±3.7 | 2.0±3.6 | 4.9±4.3 | 4.6±4.2 | IS |
| Low and medium cloud cover—Southern Ontario | 2.6±4.1 | 2.7±4.3 | 2.7±4.0 | 2.7±4.0 | IS |
| Low and medium cloud cover—South of Lake Erie | 0.77±1.8 | 0.00±0.0 | 2.8±4.0 | 2.3±3.7 | IS |

IS = insignificant (< 95% confidence level); HS = highly significant (⩾ 99.7% confidence level).

$\frac{\text{observed less expected number of days}}{\text{standard dev. of expected number of days}}$ was compared with a table of values of *t* to establish the degree of significance of the observed-expected difference. The smaller the number of days used, the larger the observed-expected difference to standard deviation ratio must be to be significant at any confidence level. In practice, when dealing with the over 30 days, the correlation is significant (at the 95 per cent confidence level) when the observed-expected difference is twice the standard deviation and highly significant (99.7 per cent level) when the difference is three times the standard deviation. These data appear in Table 1.

A second method of analysis was used for numerical parameters such as temperatures, fractions of the sky cloud covered, and wind velocities. The arithmetic means of each parameter for all types of days together and for each type of day singly were calculated. The differences between the means of

TABLE 3

MEANS OF NUMERICAL WEATHER PARAMETERS FOR THE BEGINNING AND END OF A MAJOR MIGRATORY WAVE

| | Arithmetic mean ± standard deviation | | | |
|---|---|---|---|---|
| Weather parameter at 0100 EST | All days together | 1st Type-A day of wave | Day before 1st Type-A day of wave | Day after last Type-A day of wave |
| Units: F | | | | |
| Temperature—Toronto | 49.2±8.6 | 56.6±5.8 | 52.2±10.2 | 52.8±8.1 |
| Temperature—South of Lake Erie (Cleveland, Columbus, Pittsburgh) | 53.0±8.9 | 63.4±4.8 | 56.4±3.7 | 60.7±5.9 |
| Temperature increase over day before—Toronto | 0.29±8.6 | 4.4±8.6 | 6.0±8.8 | –4.8±4.4 |
| Temperature increase over day before—South of Lake Erie | –0.01±8.4* | 7.0±5.8 | 8.0±6.3 | –3.5±4.4 |
| Temperature—Dew point interval increase over day before—Toronto | 0.01±6.3 | –9.4±8.1 | 2.8±5.1 | 0.33±4.3 |
| Temperature—Dew point interval increase over day before—South of Lake Erie | –0.08±5.5 | –2.6±5.4 | 0.67±3.7 | –2.7±4.9 |
| Units: Knots | | | | |
| Wind velocity—Toronto | 7.0±4.5 | 7.0±4.0 | 6.7±3.1 | 5.8±1.9 |
| Wind velocity—South of Lake Erie | 6.4±2.6 | 8.2±2.0 | 6.7±2.6 | 6.3±2.3 |
| Units: Tenths of Sky | | | | |
| Cloud cover—Southern Ontario | 4.5±4.3 | 4.2±4.7 | 2.2±3.6 | 5.2±4.3 |
| Cloud cover—South of Lake Erie | 4.6±4.2 | 5.0±3.3 | 5.0±3.9 | 4.3±4.4 |
| Low and medium cloud cover—Southern Ontario | 2.7±4.0 | 4.0±4.9 | 1.7±2.9 | 2.8±4.1 |
| Low and medium cloud cover—South of Lake Erie | 2.3±3.7 | 2.0±2.5 | 1.8±3.7 | 0.17±0.37 |

* The overall daily increase derived from the slope of a least squares line through a scatter plot of the daily 0100 temperatures was 0.18°F.

type-A and type-C days were tested for significance using the "*t*-test." These data appear in Table 2. The means of the numerical parameters for the first and last type-A days of a wave and for the day before the first type-A day of a wave were also calculated in order to determine the conditions when mass movements begin and end. This set of results appears in Table 3.

## RESULTS AND DISCUSSION

The results of this study are presented in Tables 1–4. These results are interpreted and discussed below.

*Migration correlated with wind and pressure systems.*—Following winds were highly significantly associated with migration of both types A and B into

TABLE 4
MIGRATION WITH WIND FOLLOWING COMPARED TO MIGRATION WITH WIND NOT FOLLOWING IN VARIOUS TEMPERATURE RANGES

| 0100 temperature (F) | Wind following, no rain | | | Wind not following, no rain | | |
|---|---|---|---|---|---|---|
| | No. A days | No. C days | No. A days / No. C days | No. A days | No. C days | No. A days / No. C days |
| 31–35 | 0 | 0 | — | 0 | 1 | 0 |
| 36–40 | 0 | 0 | — | 0 | 6 | 0 |
| 41–45 | 0 | 0 | — | 0 | 10 | 0 |
| 46–50 | 0 | 2 | 0 | 0 | 8 | 0 |
| 51–55 | 0 | 2 | 0 | 0 | 11 | 0 |
| 56–60 | 2 | 0 | ∞ | 1 | 3 | 0.3 |
| 61–65 | 4 | 0 | ∞ | 0 | 2 | 0 |
| 66–70 | 4 | 0 | ∞ | 1 | 2 | 0.5 |
| 71–75 | 1 | 0 | ∞ | 0 | 0 | — |

Ontario. The differences between the observed and expected numbers of times type-A migration occurred with following, side, opposing, and calm winds were, respectively, positively highly significant (+HS), negative and insignificant (–IS), negatively highly significant (–HS), and negative and insignificant (–IS) (Table 1). For type-B days, the correlations were similar, but, except with side winds, less significant. Following winds are the only winds positively correlated with type-A or -B migration, and opposing winds are highly significantly disassociated with major waves.

Since wind directions are largely determined by the locations of pressure systems, air masses and wind must be considered together. The flow of air around high pressure areas (highs) is clockwise, while that around low pressure areas (lows) is counter-clockwise. Thus, southerly winds are found with a high to the east and/or a low to the west.

In the present study, type-A days were highly significantly correlated with highs to the east, lows to the west, and with both simultaneously. The percentage of the days with lows to the west that were type A was greater than the percentage of the days with highs to the east that were type A. However, the percentage of the days with both a high to the east and a low to the west that were type A was still greater. The number of type-A days on which there was neither a high to the east nor a low to the west was much lower than can be ascribed to chance (–HS). All of the correlations between air masses and type-B days were similar to the air mass and type-A day relationships, but less significant. Thus, most migration occurs with a pressure gradient falling from east to west.

In general, the migration into Ontario was found to correlate with the air mass situations described above at higher degrees of significance when the wind was following than when it was not. The observed-expected differences for type-A migration correlation with highs to the east, lows to the west, and with both simultaneously were all +HS when the wind was following compared to all −IS when it was not following. The set of negative correlations with other than following winds would probably have been more significant if more data had been available. Minor waves were associated with the pressure systems as above to higher degrees when the wind was following than when it was not, but only the high to the east, wind not following situation was negatively correlated with type-B migration. Following wind, some factor accompanying following wind, or a combination of such factors, but not pressure system locations, influences migration when the pressure gradient falls from east to west.

The present study does not support the generally held view that light winds are favorable and strong winds unfavorable for migration. While the mean 0100 wind speeds at Toronto and south of Lake Erie were both lower on type-A than on type–C days, neither type A–type C difference was significant (Table 2). Furthermore, the average wind speed on the first type-A day of a wave south of Lake Erie where the flights probably originated (8.2 knots) was above (but not significantly) both the average for all type-C days (6.7 knots) and the average for the day after the last type-A day of a wave (6.3 knots). This indicates that, on the average, migrants began to move while the wind speed was higher than when most birds were not moving and while it was higher than when migration was halting.

The 0100 wind speeds never exceeded 15 knots south of Lake Erie and did so only two times at Toronto. It appears likely that at the relatively moderate speeds prevalent at night during late spring in central North America, wind strength has little effect on the volume of migration.

*Migration correlated with the presence of fronts.*—Warm fronts were classified as being to the S or W or as being to the N or E. These categories are synonymous with those of being about to pass through or having recently passed through southern Ontario. For type-A migration, there was a + IS correlation with warm fronts to the S or W and a +HS correlation with warm fronts to the N or E. The arrival of two major waves with quasi-stationary fronts (classified as warm) just south of Lake Erie was responsible for the slight positive correlation with warm fronts to the S or W. While the surface winds are not normally following before the arrival of a warm front, the upper winds can be (see Raynor, op. cit.). After warm fronts have passed through, there is usually a low to the west and south-westerly winds, both of which have already been seen to be associated with mass migration.

Cold fronts were classified as being to the N or W or as being to the S or E of southern Ontario (i.e., being about to pass through or having recently passed through, respectively). For type-A migration, there was a +HS correlation with cold fronts to the N or W and a significant negative correlation (–S) with cold fronts to the S or E. The +HS correlation with cold fronts to the N or W was probably caused by the association of these cold fronts with warm fronts to the N or E centered in the same low pressure areas. The –S correlation with cold fronts to the S or E could be caused by the rain accompanying the fronts and the opposing winds behind them. The negative correlation might have been more significant if grounded waves could have been distinguished more readily from onrushing ones.

The relationships between migration and warm sectors were tested. For this study, a warm sector was defined as the area across which a warm front had passed and a cold front was about to (and later did) pass. The correlation with type-A migration was +HS; that with type-C migration was –S. The statement of Bagg, et al. (1950:13) that "pronounced movement will take place into or through a given region during the interval between the passage of a warm front through that region and the subsequent arrival of a cold front" is supported.

Both warm and cold fronts ordinarily involve warm southerly winds on the side upon which migration occurs, rain and strong variable winds at the frontal area and cold opposing or side winds on the other side. Thus, the type of front being encountered by vernal migrants in flight is not overly important: birds meeting either type of front are usually grounded by the opposing winds and rain.

*Migration correlated with temperature.*—The present study indicates that both high temperatures and increases in temperature are *associated* with heavy migration. The mean 0100 temperature in Ontario and south of Lake Erie were very highly significantly higher on type-A days than they were on type-C days. The type-A day–type-C day differences were 11.6 F and 13.5 F respectively in the two areas. One cannot explain the higher type-A day temperatures on the basis of normal seasonal increases in temperature, for a least squares line through a scatter plot of the 0100 temperatures south of the lower lakes shows a daily increase of only 0.18 F from 50.4 F at the beginning of the coverage period to 56.0 F at the end of the coverage period. In addition, over half of the type-A days (8 of 14) occurred in the first half of the coverage period. As expected, the mean temperatures in both areas on the first type-A day of a wave were slightly less above the type-C day means than were those for all type-A days. Nevertheless, the first type-A day–type-C day differences were significant at the 99 per cent level in both areas. The mean temperatures in both areas on the day before the first type-A day of a wave were less than those on the first type-A day. However, they were greater than the means for type-C days. The mean 0100 temperature increases from the day before to the day of the first type-A day of a wave were 4.4 F in Ontario and 7.0 F south of Lake Erie. Neither increase was significantly above the mean daily increase for the coverage period, but that for south of Lake Erie was almost so. The mean increases from two days before to the day before the first type-A day of a wave were 6.0 F and 8.0 F for the respective areas. The 8.0° increase for south of Lake Erie was significant. The mean increases from two days before to the day of the first type-A day of a wave (10.4 F and 15.0 F, respectively) were highly significant in both areas. These results suggest that any influence of temperature on the initiation of migration would be cumulative and gradual. However, we have not yet determined if temperature itself does *influence* migration.

Temperature has been considered by some to have a direct influence on the timing of migration. Lack (1963), working in England, presented data to show that both temperature and wind direction exerted direct influences on spring migration. However, Raynor (op. cit.) attributed no importance to temperature during spring in eastern North America. In Illinois, Graber and Cochran (op. cit.) considered the influence of temperature to be subordinate to that of wind direction in both spring and fall. Hassler, Graber and Bellrose (1963) believed that temperature was not of primary importance in Illinois in the fall.

On the day after the last type-A day of a wave, the mean 0100 temperatures in the two areas were lower than on the preceding day but still above the means for the coverage period. At Toronto, the mean temperature drop from the day of to the day after the last type-A day of a wave was 4.8 degrees to 52.8 F (the overall mean for the coverage period was 49.2 F). South of Lake Erie, the drop was only 3.5 degrees to 60.7 F (the coverage period mean was 53.0 F). It seems unlikely that these small and statistically insignificant decreases in temperature could in themselves stop a mass movement. Furthermore, the lower mean temperatures per se could not stop the birds for they were still above the seasonal averages. By considering the mean and standard deviation of the temperatures on the first type-A day of a wave in both areas. about one-fourth of the major waves would be expected to start with temperatures lower than the means for the day after the last type-A day of a wave. In fact, of the six major waves for which data are available, one began with a temperature at Toronto lower than the mean Toronto temperature on the day after the last type-A day of a wave and two began with a temperature south of Lake Erie lower than the mean there on the day after the last type-A day of a wave. It seems likely that factors other than temperature and changes in temperature are responsible for the termination of mass migrations. In particular, changes in other weather parameters and decreases in the supply of birds physiologically ready to migrate must be considered.

It should be recognized that the correlations between migration and *mean* temperatures investigated here may be oversimplifications. While there was a highly significant correlation between high temperature and type-A migration, one major wave began with a temperature at Toronto of less than the type-C day mean. Further discussion of the importance of temperature to the timing of migration appears later.

*Migration correlated with humidity.*—While it seems unlikely that humidity influences the timing of mass migration, there was some correlation between the two. There were no consistent or significant differences between the different types of days in the mean size of the interval between the 0100 temperature and the 0100 dew point. This indicates that the value of the relative humidity is not correlated with variations in the volume of migration. However, it was found that the mean actual temperature—dew-point-temperature differences had decreased in size from the previous day on major wave days in general and on the first major-wave day of a wave in particular. On little movement days, the mean difference increased slightly in size. The change in size of the interval from the previous day was highly significantly different on type-A days from what it was on type-C days at Toronto, but insignificantly different south of Lake Erie. Thus, there is some correlation between major waves and increasing relative humidity. However, it had also increased on the day after over the day of the last type-A day of a wave south of Lake Erie by about the same amount that it had increased over the previous day on the first type-A day of a wave. Increasing relative humidity could hardly help both to start and to stop a mass movement. While no analysis was done, it was apparent that the absolute humidity (the amount of water vapour present per unit of volume of air) as indicated by the dew point value itself was correlated with migration much as temperature was (i.e., Type-A migration occurred with high and rising absolute humidity).

Graber and Graber (1962:81) suggested that conditions with high humidity "may be optimum for migration, because of the effect of such conditions in reducing dehydration." However, the marked influence of warm southerly winds appears to be of much more importance to the timing of flights than is the influence of these inconsistent, less statistically significant humidity changes. Since high humidity is usually concurrent with the other significantly associated factors, perhaps the commonly used term, "warm southerly winds" should read, "warm, moist southerly winds."

*Migration correlated with cloud and rain.*—Correlations were made between migration and the amounts of sky covered at 0100 both by all kinds of cloud and by only low and medium cloud. The average amounts of sky covered by each of these cloud classifications both in Ontario and south of Lake Erie were all insignificantly less on type-A days than on type-C days. The differences in the averages between the two types of days were very slight except for the almost significant difference between the average amounts of low and medium cloud on type-A and type-C days south of Lake Erie. Although four of the 13 major wave days for which data are available had 0.7 or more of the sky cloud covered south of Lake Erie, the cloud was opaque on only one of those days. No type-A day had total overcast south of Lake Erie.

While these results suggest that cloud is unfavorable to migration, there were other contradictory data. The average total cloud cover south of Lake Erie on the first type-A day of a wave (0.50) was insignificantly greater than that on little movement days (0.49). In addition, the average cloud cover of both classifications in both areas had not decreased from the day before on the first type-A day of a wave. The large and increasing average amounts of cloud on the first days of waves were caused by the proximity of fronts. Warm fronts often moved through just before the arrival of the first birds of mass movements. Many of these birds probably started flying in clearer weather and then overtook the warm fronts which advanced at an average speed of only 11 knots (calculated from positions at 12 hour intervals on the weather charts). Thus, it would appear that cloudy weather is less favorable to migration than is clear weather, but that the amount of cloud cover as a determinant of the volume of migration is of secondary importance. Hassler et al. (op. cit.) suggested from autumn radar studies that "some migration does occur on nights of complete overcast," but that "not all birds in the migratory state will depart under overcast skies."

The present study supports the commonly accepted view that rain is unfavorable to migration, but not as strongly as might be expected. The difference between the number of major-wave days that had rain and the number expected if migration were not affected by rain was only −1.7 times the standard deviation (−IS). This would be significant at the 90 per cent confidence level, but not at the accepted 95 per cent level. Several type-A movements on days which were classified as having rain probably missed the precipitation by arriving at a different time or place. Thus the disassociation between rain and migration would have been more significant if we knew which birds actually did encounter rain.

*Wind direction vs temperature as a determinant of the volume of migration.* —While all authors agree that both wind direction and temperature are correlated with the varying volume of migration, they disagree on which factor actually influences the volume. The difficulty in analysis has been in separating the effects of high temperature and following wind which usually are concurrent. I believe that the methods used here can successfully separate the effects, but more data will be required for a final answer.

In order to determine if temperature had a direct influence in causing type-A migration, the mean temperatures south of Lake Erie for type-A and for other types of days were compared when simultaneously there was a following wind, a high to the E and/or a low to the W, and no rain. The mean on type-A days was 64.9 ± 3.9 F; that on other types of days was 52.4 ± 7.3 F. The difference is very highly significant. Thus on different types of days, the temperatures were highly significantly different ($P < .001$), while other important weather factors (including wind direction) remained essentially constant. Hence, the volume of migration can be influenced directly by temperature.

Table 4 was designed to show whether wind direction could have a direct influence on the volume of migration. It indicates the number of type-A days and the number of type-C days in several 0100 temperature ranges both when the wind was following and when it was side or opposing. Only those days on which there was essentially no rain either below Lake Erie or in southern Ontario were used. Within individual temperature ranges, we are able to compare the frequencies of major-wave days under conditions differing only in wind direction, for the temperature is nearly constant (ranges only 5 F wide) and there is no rain.

It is seen that the ratio of the number of type-A to the number of type-C days under the condition of following wind is greater than or equal to the corresponding ratio under the condition of side or opposing wind in all temperature ranges in which the ratios both exist. Furthermore, the ratios are equal only when they are both zero. This suggests that wind direction can have a direct influence on the timing of migration. A chi-square test in each temperature range, however, shows that in none of the ranges is there a significant difference between the proportion of A to C days with following and the proportion with side or opposing winds. This probably indicates that not enough days are present in each range. When all of the ranges above 55 F are grouped together, there are 11 type-A days and no type-C days with following winds compared to two type-A days and seven type-C days with side or opposing winds. For this combination of ranges, $\chi^2 = 10.0$, indicating a high degree of significance ($P < .005$) in the difference of the proportions of A to C days with different wind directions. It was considered at least partially justifiable to group the ranges above 55 F together because above that temperature, all days with following wind were type-A. Hence a further increase in temperature (above 55) when the wind was following could not possibly have stimulated more type-A days. We can conclude that wind direction probably does have a direct influence on the volume of migration, but further work with much larger quantities of data will be necessary for a more definite answer.

It has already been shown that the mean decrease in temperature on the day after over the day of the last type-A day of a wave is too small to stop mass migration. Since the mean temperature increased by several degrees from two days before to the day before the first major wave day of a wave in addition to increasing from the day before to the day of the first day with mass migration, rising temperatures appear to be unable to cause rapid changes in the volume of migration. This supports Lack's view (1960*a*). None of the days used in Table 4 with 0100 temperatures south of Lake Erie of less than 59 F were type A. All of the days in Table 4 with 0100 temperatures of 59 F or above were type A if the wind was following; 2 out of 9 were type A if the wind was side or opposing. This suggests that the temperature must be above a certain value for major waves to occur and that above this value, wind direction exerts the dominant influence on the volume of migration. This indication is in agreement with the results of Lack (1963) in England.

## SUMMARY

This paper presents an analysis of correlations between the volume of bird migration into southern Ontario during the late spring in 1961, 1962, and 1963 and various weather parameters.

Following winds and high temperature are correlated with major waves of migrants, but changes in temperature by themselves do not appear to be able to cause immediate changes in the volume of migration. The data suggest that mass migration takes place only when the temperature is above a limiting value but that above that value, wind direction exerts the major influence on the volume of migration. Very little migration occurs without warm following winds. Since warm following winds are caused by high pressure areas to the east and/or lows to the west, these pressure situations are positively correlated with major waves. They themselves have a negligible influence on migration. There is a negative correlation between rain and major waves, but it is not as highly significant as might be expected.

Fronts, warm sectors and changes in humidity showed significant correlations with the volume of bird movement. These factors do not themselves influence migration significantly, but they are associated with other factors (wind direction, temperature, rain) which do.

Wind speeds, the amount of cloud present and the relative humidity showed no consistent or significant correlations with the volume of bird migration.

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